Final Technical Report

DEVELOPMENT OF AN MPT MANAGEMENT SYSTEM

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SUMMARY

This contract (ONR: N00014-00-C-0270) has resulted in two deliverables, apart from this final report. The first deliverable is a software application intended primarily to facilitate officer detailing in the U.S. Navy and other military agencies. It may also be useful in civilian organizations with complicated personnel assignment or reassignment needs. The second deliverable is a design of software intended to facilitate enlisted career counseling in the U.S. Navy and other large civilian or military organizations.

The primary feature of the first deliverable, tentatively entitled DETAILER, is that it is based on two-sided matching. Thus all matchings assigned by the program are stable. No officer and command both prefer each other to the billet and officer assigned them.[1] The officer may prefer other billets but those commands prefer the officers assigned to them. Similarly, a command may prefer other officers to the one it has been assigned but those officers prefer the billets they have been assigned. Other features of DETAILER are:

—The program recognizes that officers typically change jobs every few years. The user can make exceptions if he or she chooses but ordinarily each officer has a transfer date when he or she is expected to move to another job.

—The program takes account of rank. The default condition is that an officer can be assigned to a billet rated at the officer's current rank or one rank above or below it. Again, the user can make exceptions if he or she chooses.

—The program takes account of transfer dates. The user can specify how long a gap (how many months) there may be between the departure of the incumbent officer and the arrival of his or her replacement. Similarly, the user can specify how much overlap (how many months) there may be when both officers are on board. Again, of course, the user may make exceptions.

Most importantly, the program allows the user to take into account the preferences of individual officers and commands. The officers do not have to rate or rank all billets; nor do the

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[1] We will speak of officers preferring billets and commands preferring officers. Where a particular billet is at issue, it is the command's preferences for that billet to which we refer. Similarly, although the command may be a part of it, an officer's preference is for a particular billet, not the command itself.

commands have to rate or rank all officers. But wherever the user knows of an officer's or a command's distinct preference, that preference can be taken into account.

—DETAILER eventuates in a slate of assignments, a one-to-one pairing of officers and jobs. Ordinarily, all or most of those assignments are made by the program, after allowance is made for rank, transfer dates, and individual preferences. However, the program allows the user to make assignments manually.

The second deliverable responds to the Navy's need for its career counselors to have a systematic basis for their work. A sailor approaching his rotation date needs to know several things: which jobs are available, which of those jobs he is eligible for, the probabilities of obtaining particular jobs, how his expressed preferences might affect those probabilities. If he has an idea where he would like to be several tours into the future, how (by which career pathways) might he reach that goal and what are the probabilities of his reaching it by one or another of those possible pathways?

The second deliverable is based on representative samples of sailors with the same rate and rating, rather than historical data. Historical data are notoriously difficult to ascertain and, even when they can be ascertained, they are necessarily out of date. Further, they involve only the pathways that other sailors have followed, not their preferences. A sailor, however, needs to know not only what his options are but how his expressed preferences are likely to affect his probable assignment. That, after all, is why he meets with a counselor, to decide what to ask for.

The proposed solution results in a figure showing each job a sailor is eligible to have and the probability of his being assigned to it *given his expressed preferences*. The sailor may not like what he sees, in which case he may consider another set of preferences and see how it turns out. Meanwhile the counselor can inform him about the jobs he is considering and point out to him the value of making realistic preferences. The two together can consider possibilities not just for the next tour but the one after that and others still further into the future.

The remainder of this report is divided into four sections, plus appendices. The next section outlines the contract's history. The section after that explains two-sided matching. And the final two sections explain the two deliverables.

CONTRACT HISTORY

The original proposal called for two deliverables: "The first is a stand-alone package for use in personnel situations characterized by many jobs, small quotas (often just one person),

and many constraints on who can be assigned where. This first package is focused primarily on constraint satisfaction, that is, on assignments that meet all rules, regulations, individual preferences, and other requirements or desiderata as well as possible. The second and more complex package is intended for use in personnel situations characterized by large numbers of people to be assigned, few job categories, and many individuals to be assigned in each category…Our intention is to carry Package 2 as far toward market readiness as we can but we do not expect to get there in this contract."

We (Joseph and Jones) travelled to Millington at the very start of the contract, August 16-19, and met with Tanja Blackstone, Tony Benson, and Steve Clemens. Work proceeded as planned and in midDecember we submitted a "First Progress Report" (Appendix A). In February, 2001, we returned to Millington and presented our results to date to Blackstone, Benson, and Clemens. Then in March we made the same presentation to Tony Cunningham. At the meeting with Cunningham we learned that he, as head of the Sailor/Marine Career Management System, was organizing a Military Personnel Research Science Workshop to be held at the University of Memphis on June 4-5, 2001. We were invited to attend and to present.

At the workshop we were greatly impressed by the presentations involving two-sided matching, especially the one by Bill Gates. We had expected from the beginning to rely on constraint satisfaction. However, after reading the basic text on two-sided matching by Roth and Sotomayor [1990] we became convinced that it offered a theoretically superior constraint to the one we had originally envisioned. Accordingly, on June 15, we wrote a letter to Cunningham (Appendix B) suggesting that we move our theoretical base to two-sided matching and requested a "steer" from him as to where we might now take our work. He replied that he wanted to talk over our proposal with "Tanja Blackstone and other folks in my institute" We next heard from Tanja, who told us that the "alternate approach" that she and Tony had discussed was to undertake the "carrer path/career development piece of the S/MCMS." We indicated that we felt we should finish Package 1 of our original proposal (with the theoretical base now moved to two-sided matching) and then get as far as we could with the career management work (which now replaced our original Package 2). We then met with Tony Cunningham as soon after that as was possible (August 9, 2001) and obtained a more definite idea of what we might do with career management. Almost a year later (July 22, 2002) we presented our thoughts and ideas to Tony. In the meantime DETAILER was nearing completion.

We requested and received a no-cost 6-month extension to prepare both projects for final presentation in this report and accompanying software.

TWO-SIDED MATCHING

Two-sided matching is a branch of game theory used by economists to model markets which include two disjunct sets of agents. In a conventional commodity market the agents are not disjunct. Today's buyer may become tomorrow's seller. "Buyer" and "seller" do not refer to two nonoverlapping groups of people but to two roles that the same agents may play. Further, what one sells and what one buys do not have any obligatory relation to one another. The same man who sells his car may buy a television set and the person who buys the television set may sell it and buy something else tomorrow. A matching market contrasts sharply in these respects. In a labor market workers look for firms to hire them and firms look for workers to hire. The workers may leave the firm and the firm may discharge the worker but neither one in so doing becomes the other. Further, when a worker finds a job, it is with another firm and that firm, on its side, finds that individual as a worker. There is a necessary complementarity between the two, a matching of one or more agents from one side with one or more agents from the other. This complementarity is especially obvious in a marriage "market." Men look for women and women look for men. When they marry, there is a matching of one man with one woman and vice versa.

In two-sided matching the marriages are usually arranged, although they do not have to be; matching theory can also be used to describe or explain human behavior in natural markets [for example, Becker, 1973, 1974; Grosbard-Schechtman, 1984; McElroy, 1990]. The first application of two-sided matching, and still its most successful, is the National Resident Matching Program (NRMP). Medical students in their fourth and last year of training for the M.D. degree start looking for residency programs to train them in a specialty. They visit at least a few such programs and, on this basis and what is generally known about the programs, they submit their preferences to the NRMP. The list begins with the student's most preferred program, then his or her second most preferred program, and so on; the list may be as long as the student wishes to make it. On their side, the residency programs submit their preferences to the NRMP. Their lists name the students the residencies would like to have in order of preference. The two sets of lists are then processed by the NRMP and on Match Day in the second week of March both students and residency programs learn who has been assigned where.

The relevant medical associations agreed to adopt the NRMP procedure for the 1951-52 academic year and have been using it ever since. The algorithm used by the NRMP to process the lists of preferences was developed partly by good sense and partly by preliminary trials. It was 32 years later when Roth [1984] showed that the NRMP algorithm had been developed from theoretical considerations twenty-two years earlier by Gale and Shapley [1962] in a paper entitled "College admissions and the stability of marriage."

"Stability" is the central idea in matching theory. It applies to matchings, that is, one-to-one pairings of men and women or, more generally, of agents from one side of the market to agents from the other. To be stable a matching must meet two requirements. First, the paired agents must be acceptable to each other. If a man would rather be single than married to the woman assigned to him, the marriage is unstable—and similarly, of course, if a woman is assigned an unacceptable man. Second, a matching is unstable if it includes a man and a woman who would rather be married to each other than to the persons assigned them in the match. If there were such a couple, then both man and woman would be better off outside the match than in it. If they can find each other, they will both, in theory, abandon their assigned mates and form their own couple. In the NRMP a student who can find a residency which he prefers, and which prefers him to at least one of the students assigned to it, has no compelling reason to accept the assignment made for him by the NRMP. He or she can do better on his or her own. On the other hand, if every residency which the student would prefer has other students it prefers to her, then the student has done as well as she can expect. Yes, there are residencies the student would prefer, but those residencies don't want her. As for the residencies, they would like to have some students more than the ones they have, but those students are all in programs they prefer. So both sides settle for the match.

For several major reasons military services worldwide rotate their personnel from job to job every few years. Some jobs are less attractive than others and good morale is better served by equitable rotation than by allotting good jobs to some people and poor jobs to others on a standing basis. Military readiness typically requires proficiency in a variety of skills under varied circumstances, and rotation better meets this requirement than long-continued assignment to one job. Military services do not want their personnel to put down such strong roots in one place that they resist reassignment when the occasion requires it. The word "detailing" refers to the process of reassigning military personnel from one job to another; it ap-

plies to both officers and enlisted men; and the people who make these reassignments are called "detailers."

Detailing is a two-sided matching process, a special kind of labor market. It has two sides, officers and billets. The officers have their preferences among available jobs and the commands have their preferences among available officers. The detailer's task is to make assignments that meet both sets of preferences as well as possible. The idea of stable matching clearly applies. It makes no sense to assign an officer to one job when he would prefer another job in another command and that other command would rather have him than the officer assigned to it. In these respects the detailing process parallels the marriage market or the residency market for graduating medical students.

THE FIRST DELIVERABLE: DETAILER

Program Overview

The Detailer program is designed to employ two sided matching to aid in the process of assigning Officers to Billets. To do this, a database of officers and billets is defined. Officers and billets are associated in one or more matchings or assignment slates that can be used to make the final assignments.

The Detailer program is written in Microsoft's Visual Basic and uses an Access database. The program is organized into program screens and a Dynamic Link Library (DLL).

There are two main program screens. The first is the database development screen. It allows the user to define the Officer and Billet information. In this screen the names, dates, ranks, and ID information is set. The second screen allows the user to manipulate and analyze the matching process. In this screen the preference list order can be manipulated, manual assignments made, and the two sided auction run.

The other component is a Dynamic Link Library (DLL) that encapsulates the algorithm that implements two sided matching. This DLL can be used to incorporate into other products where two sided matching is desired, including web based products.

The following is a description of the program screens, their contents and their use.

Window 1

Database Selection Window

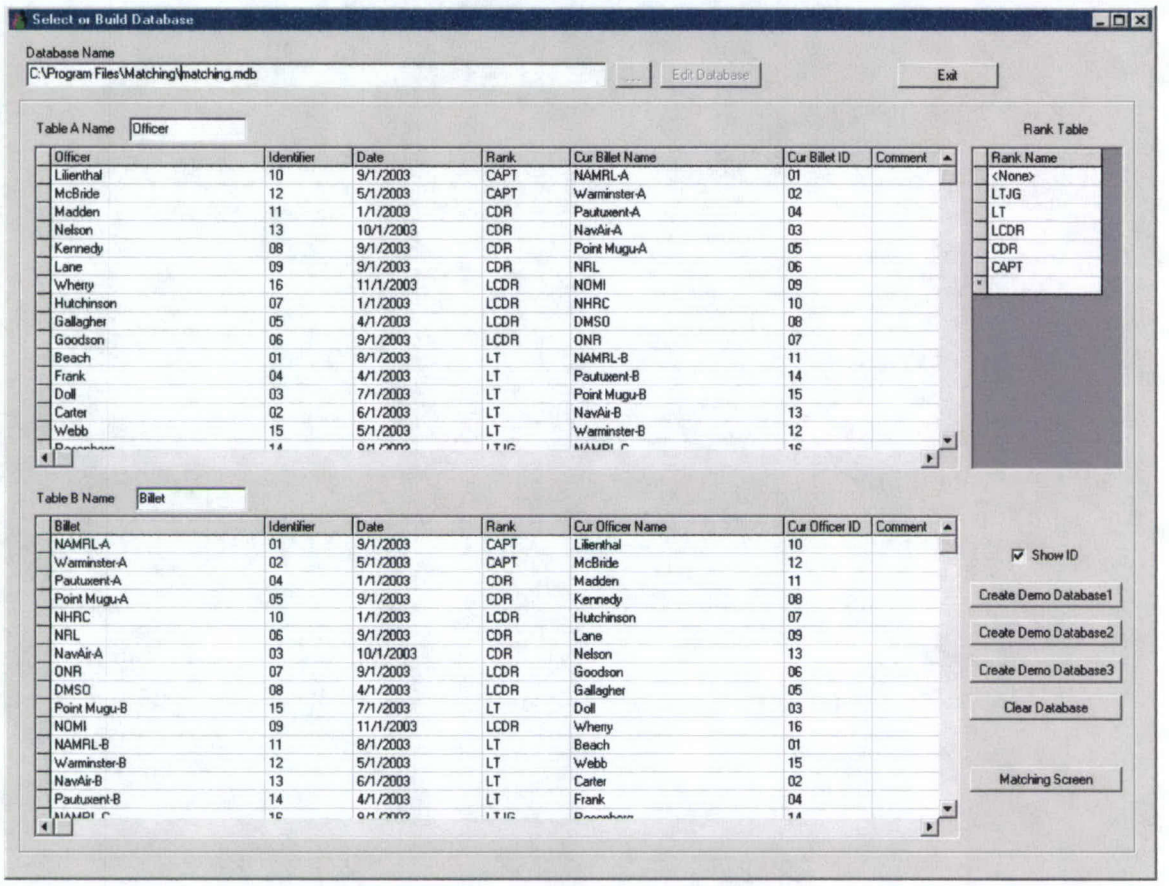
This window allows the user to select a database name to use. This is an access database that is created and used by the program.

The program begins with a default database name. Either this name, or a user defined name may be used. If the database named does not already exist, it will be created using the name supplied. If the database already exists, then the user may press the "Load and Go" button to load the database and proceed to the matching screen. Otherwise, the "Edit Database" button should be pressed.

Buttons:

- ... - Brings up a file selection dialog that allows the user to navigate disk drives and directories to find a database to load.
- Edit Database - Expands the window into the Edit Database screen.
- Load and Go - Loads the named database and goes directly to the Matching Screen.
- Exit - Exits the Detailer program.

Window 2



Edit Database

When the "Edit Database" button is pressed, the screen expands to add the database editing tables. The tables are:

Table A- Henceforth referred to as the Officer Table. This table will contain information that refers to each officer in the set of officers that the user is responsible for assigning. If the user would rather refer to placed individuals as something other than Officer, the name can be entered next to Table A Name, and all references to officer in the program will be replaced by the new name.

The columns in this table are:

- Officer - The name of the officer
- Identifier - The ID number of the officer. This field may be ignored by clicking the "Show ID" check box.
- Date - The transfer date of the officer

- Rank - The current rank of the officer
- Cur Billet Name - The current billet to which the officer is assigned
- Cur Billet ID - The ID number for the current Billet. This field may be ignored by clicking "Show ID"
- Comment - A user defined comment to be associated with this officer

Table B - Henceforth referred to as the Billet Table, contains information that refers to each billet where officers may be assigned. If the user would rather refer to the jobs to be filled as something other than Billet, the name can be entered next to Table B Name, and all references to billet in the program will be replaced by the new name.

The columns for this table are:

- Billet - Name given to the billet
- Identifier - Designation given to the billet
- Date - The date when the billet will be vacant
- Rank - The designated rank associated with the billet. Must be one of the items from the Rank Table.
- Cur Officer Name - Current officer occupying the billet. Must be either <None> or one of the names in the Officer Table
- Cur Officer ID - The ID of the current officer.
- Comment - A user defined comment to be associated with this billet

Rank table - contains a list of officer ranks in order from lowest to highest.

Data editing:

To add a row to a table, the user double clicks on the bottom row. This creates a new row, and allows the user to fill in information in the new row.

When a new officer is added, the ID, Date, Rank, and Current billet fields are defaulted. The ID field is guaranteed to be unique and need not be changed if the ID is not needed. The Date field defaults to the current day. The Rank field defaults to <None>. If rank is not needed, this field can be left as the default. The Current billet fields also default to <None>. If the program

will not need to exclude from consideration the billet an officer currently occupies, these fields could be left as the default as well.

The order of Officers in the Officer Table and the order of Billets within the Billet Table will determine the order of the initial preference lists. These lists can be modified and updated in the Matching Screen.

It is recommended that the user enter all Officers and Billets first, before modifying the Date fields or Current fields.

To modify a field, double click the mouse on that field. For the Rank, and Current fields, a menu list of all the possible options is presented. This allows the user to select a Rank, or current billet from the existing set.

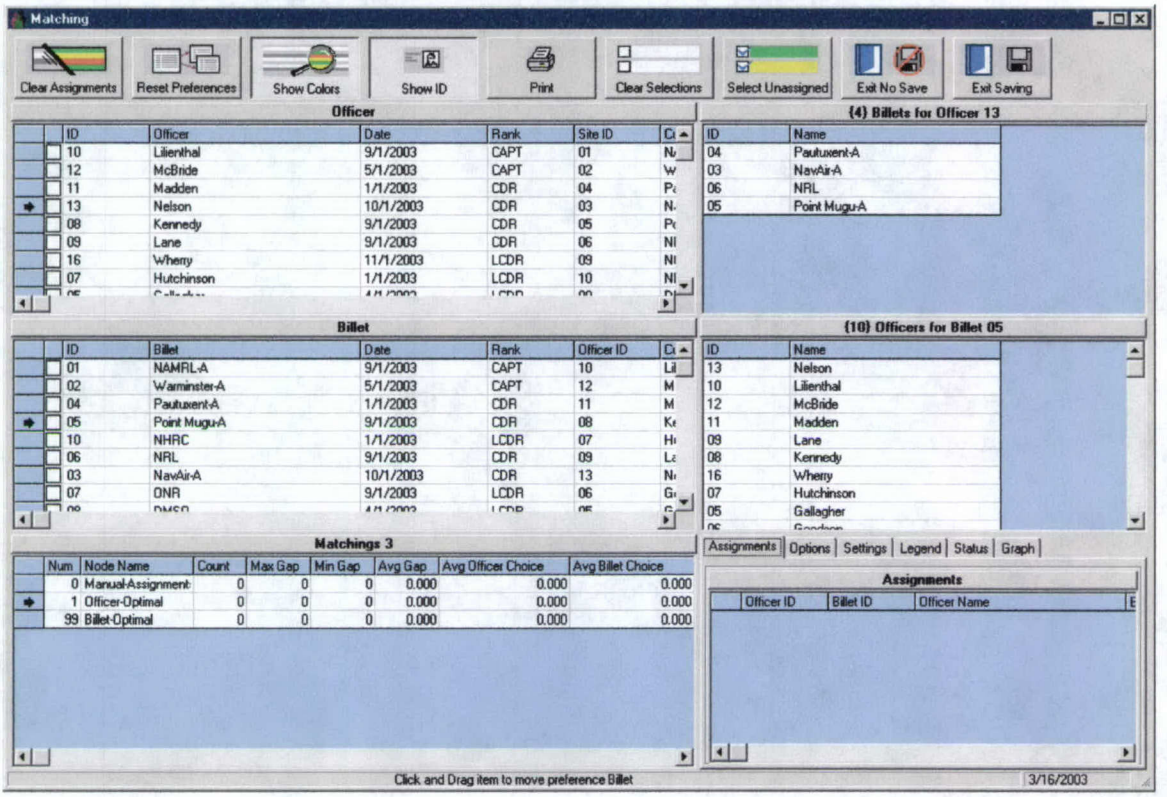
When the Cur Billet Name is selected for an officer, the Cur Billet ID is automatically selected as well, and the Cur Officer fields of the selected billet are updated to reflect the same officer. The date fields are also coordinated between officer and billet with the assumption that an officer's transfer date coincides with the date when his/her current billet is available.

The Billet Table operates in a similar fashion as the Officer Table.

Buttons:

- Create Demo Database 1 - Creates a pre-defined set of officers and billets with randomized settings for demonstration purposes.
- Create Demo Database 2 - Creates a pre-defined set of officers and billets designed to produce many matchings in the Matching screen.
- Create Demo Database 3 - Creates a pre-defined set of officers and billets designed to simulate a detailer's actual data.
- Clear Database - Clears the database allowing the user to start again creating officer and billet information.
- Matching Screen - Launches the Matching screen that allows the user to define assignments.

Window 3



Initial Matching Screen

The Matching screen consists of command buttons at the top, a set of 5 tables, plus a tab list of sub-screens with additional information and options.

- Officer Table - Contains the same information as the Officer Table from the Edit Database Screen, plus a column to indicate the currently selected officer and check box to indicate if the officer has been selected to participate in the two sided auction. Each row in this table represents an individual officer.

- Billets for Officer Table - Contains a sorted list of billets for which the selected officer is eligible. The list is to be sorted in order of that officer's preference.

- Billet Table - Contains the same information as the Billet Table from the Edit Database Screen, plus a column to indicate the currently selected billet and check box to indicate if the billet has been selected to participate in the two sided auction. Each row in this table represents an individual billet.

- Officers for Billet Table - Contains a sorted list of officers which are eligible for the selected billet. The list is to be sorted in the commands' preference for each officer.

- Matchings Table - Contains each matching or slate of assignments. Initially, this list contains 3 entries. Manual assignments that can be made one officer or billet at at time, Officer optimal assignments and Billet optimal assignments. In most cases the officer and billet optimal assignments will be the same assignment slate. However, in some cases they will be different slates and may further be seperated by further assignment slates. Double clicking on a match confirms the assignments in that assignment slate.

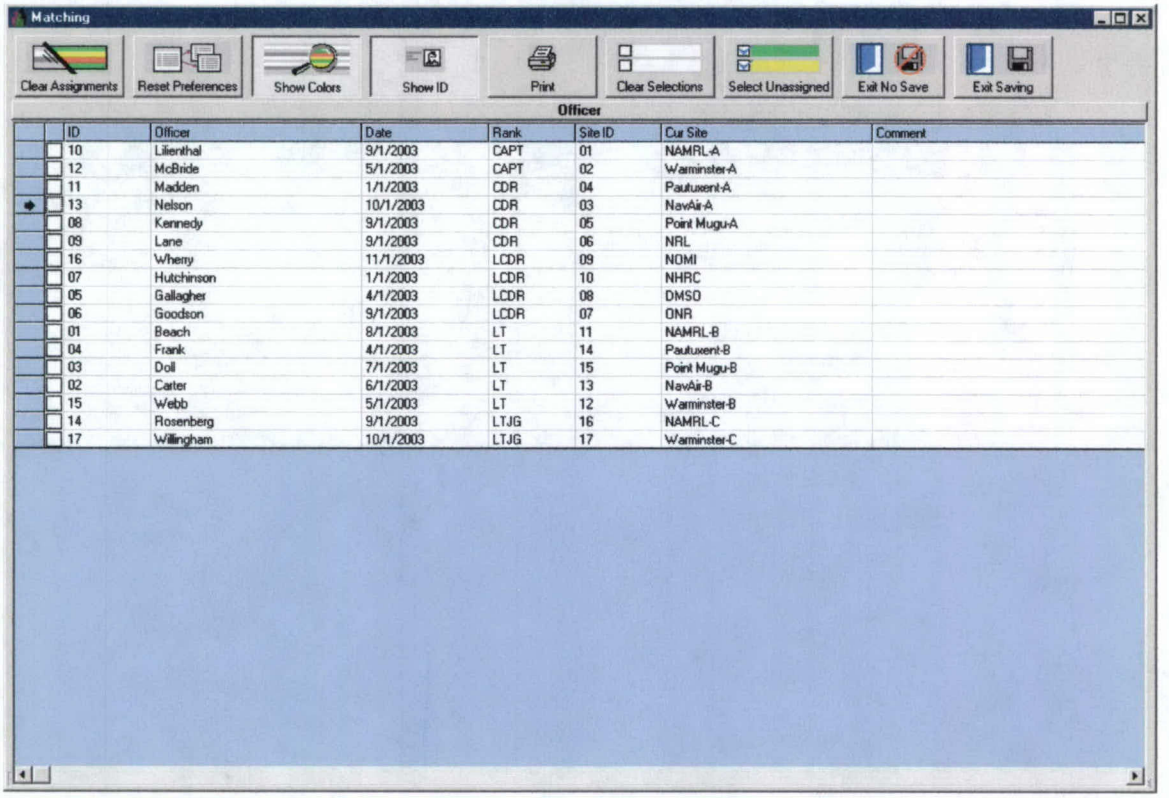
Buttons:

- Clear Assignments - Remove all manually set assignments.
- Reset Preferences - Revise all preference lists so that each officer's list contains all billets in the order of the Billet Table and each Billet's list contains all officers in order of the Officer Table. These lists are created under the date, forced transfer, and rank constraints.
- Show Colors - Toggle the display of field colors that give a color indication of the assignment status of each item.
- Show ID - Toggle the display of the ID field in each of the tables.
- Print - Print current information including Officers, Billets, preferences and assignments.
- Clear Selections - Clear all selection check boxes.
- Select Unassigned - Any officer or billet that has not been manually assigned is selected for the two sided auction. The auction algorithm will automatically be run each time items are selected. Clicking this button turns on the selection check boxes in the Officer and Billet tables. These check boxes may be set individually if desired.
- Exit No Save - Exit the Matching Screen without saving any changes to the database.
- Exit Saving - Exit the Matching Screen after saving the changes.

Above each Table is a title button. If this button is pressed, the table is expanded to fill the entire window. Click it again and the table is returned to its normal size.

At the bottom right of the screen are a set of sub-tabs, (Assignments, Options, Settings, Legend, Status, Graph). Pressing each tab brings up that sub screen.

Window 4



Expanding Officer Table

Interrelated navigation of tables:

- Each time an item is selected in the Officer Table, the associated list is displayed in the Billets for Officer Table.
- If selecting items in the Billets for Officer Table, the billet selected is displayed in the Billet table.
- Each time an item is selected in the Billet Table, the associated list is displayed in the Officers for Billet Table.
- If selecting items in the Officers for Billet Table, the officer selected is displayed in the Officer table.
- If an assignment is selected from the Assignment Table, the Officer and Billet are selected in their respective tables.
- Each time an item is selected in the Matching Table, the associated assignment slate is selected in the Assignment sub-tab. There will only be assignments when items have been selected either manually, or with the Select unassigned button.

Modifying Table Order:

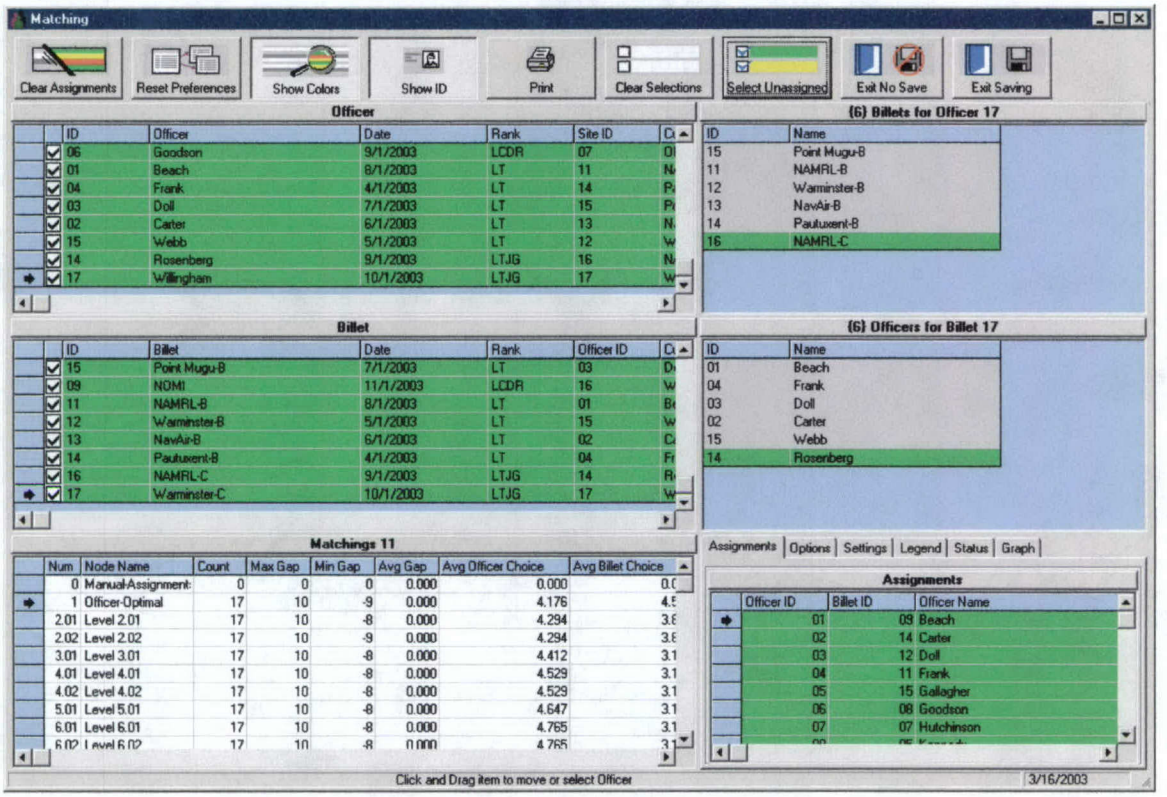
To change the order of an item in a table, click on that item and while holding the button down, drag to the location where the item should be in the table. When the button is released the item will be moved to the new location. This method can be used to move Officers in the Officer Table, Billets in the Billet Table, and preference list entries

Adding to preference lists:

To add a billet to an officer's preference list, click on the billet in the Billet Table, and drag it to the Officer's preference list.

To add an officer to a billet's rpeference list, click on the officer in the Officer Table, and drag it to the Billet's preference list.

Window 5

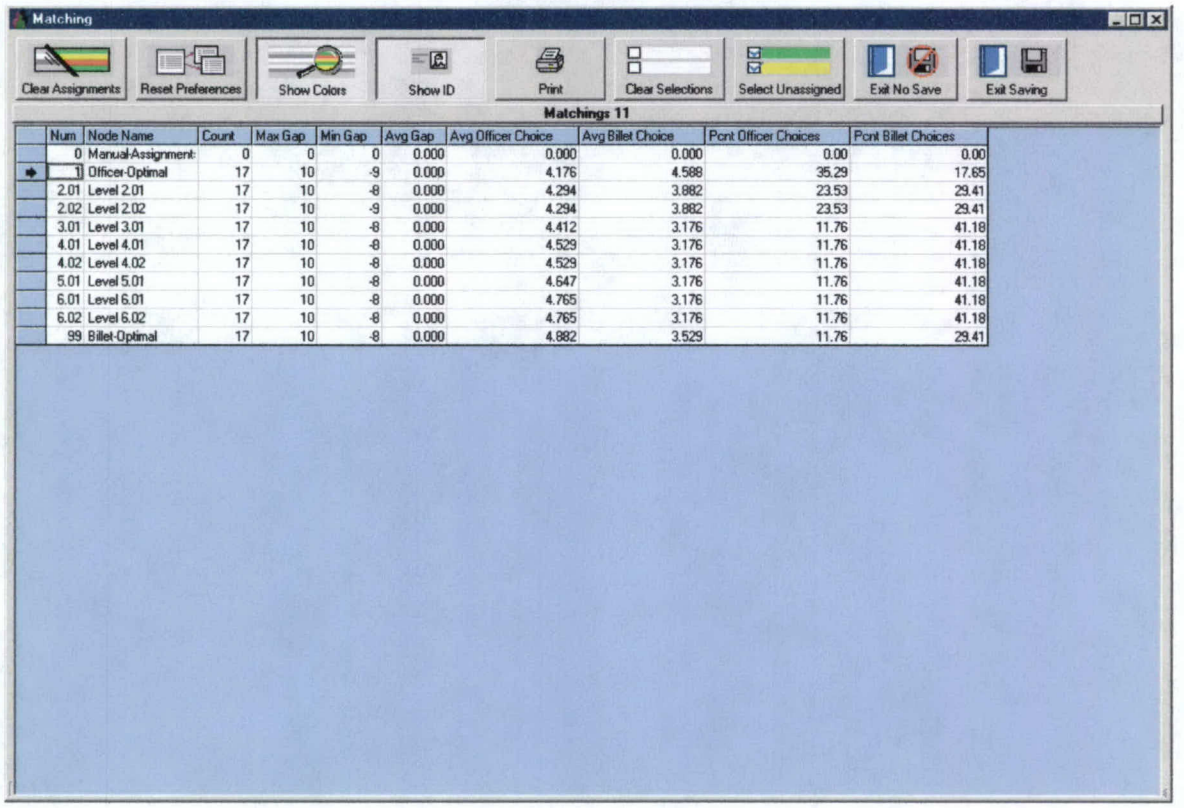


This is the Matching Screen after pressing the Select Unassigned button. Note the setting of the selection checkboxes for each officer and billet. This example shows 10 assignment slates, Officer optimal, Billet optiomal, and eight in between. Each assignment slate is indicated in the Matching Table.

Because the Show Colors toggle button is on, the selected items show up in colors based on their assignment condition.

- Green means that the item has been assigned, and the assignment is pareto optimal.
- Red means that the item cannot be assigned by the current configuration, either because the preference list is empty (no eligibility) or because all the entries on the preference list are filled by others of higher priority.
- Yellow means that the item has been assigned, but to a non-pareto optimal matching. This can only happen with a manual assignment.
- White means either unselected, or unassigned.
- Grey in the preference lists means that the item has been assigned.
- Green in the preference list means the item has been assigned to the green item.
- Yellow in the preference list means the assignment is made but non-pareto optimal.

Window 6



Num	Node Name	Count	Max Gap	Min Gap	Avg Gap	Avg Officer Choice	Avg Billet Choice	Pcnt Officer Choices	Pcnt Billet Choices
0	Manual-Assignment	0	0	0	0.000	0.000	0.000	0.00	0.00
1	Officer-Optimal	17	10	-9	0.000	4.176	4.588	35.29	17.65
2.01	Level 2.01	17	10	-8	0.000	4.294	3.882	23.53	29.41
2.02	Level 2.02	17	10	-9	0.000	4.294	3.882	23.53	29.41
3.01	Level 3.01	17	10	-8	0.000	4.412	3.176	11.76	41.18
4.01	Level 4.01	17	10	-8	0.000	4.529	3.176	11.76	41.18
4.02	Level 4.02	17	10	-8	0.000	4.529	3.176	11.76	41.18
5.01	Level 5.01	17	10	-8	0.000	4.647	3.176	11.76	41.18
6.01	Level 6.01	17	10	-8	0.000	4.765	3.176	11.76	41.18
6.02	Level 6.02	17	10	-8	0.000	4.765	3.176	11.76	41.18
99	Billet-Optimal	17	10	-8	0.000	4.882	3.529	11.76	29.41

Expand Matching Table

This window is the Matching Table after pressing the title button above the table. The columns that are included in this table are specified in the Options Sub-tab. If the check box is ON, then the column is included.

Columns:

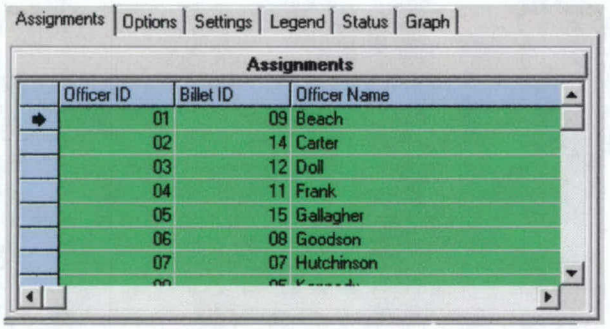
- Num - Matching level number. Manual assignments are level 0. Officer optimal assignmeents is level 1 and Billet optimal assignments is level 99. All officers would prefer the officer optimal matching. All commands would prefer the billet optimal matching. The closer the level number is to either Officer or Billet optimal the more desirable the matching is to officers or commands.
- Node Name - More descriptive node level number.
- Count - Number of assignments for the assignment slate.
- Max Gap - Maximum number of months that a billet is vacant within the assignment slate
- Min Gap - Maximum number of months that two officers occupy the same billet within the assignment slate.
- Avg Gap - Average months of gap and overlap.

- Avg Officer Choice - The average choice number that officers received in the assignment slate. If all officers got their first choice, this number would be 1.
- Avg Billet Choice - The average choice number that billets (commands) received in the assignment slate.
- Pcnt Officer Choices - Percent of officers that received their top choices. The Choice List Depth field of the Options Sub-tab determines how many items are in the top choices.
- Pcnt Billet Choices - The percentage of Billets (commands) that received their top choices.

Sub-Windows 1-7

Sub-Tabs at bottom right of the Matching Screen.

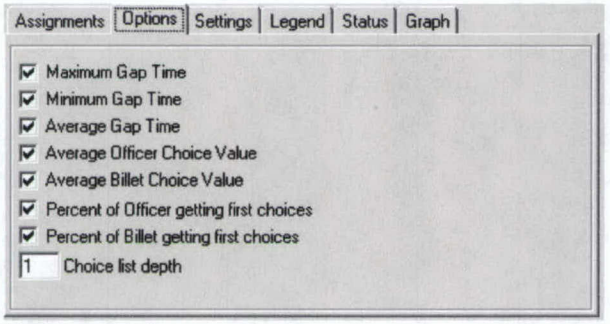
Click on the Sub-tab label to display the sub window for that tab.



Assignments Tab

Assignments

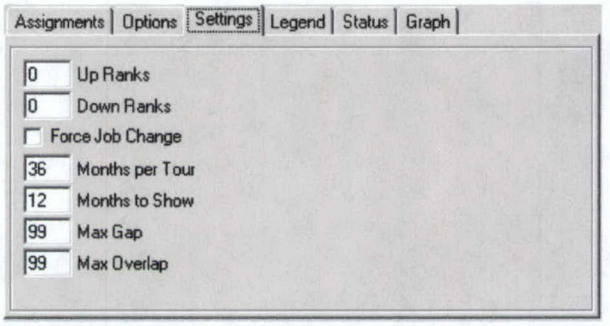
Each row in this table contains an assignment between an Officer and a Billet. Selecting a row in this table selects the Officer and Billet referred to in the assignment.



Options Tab

Options

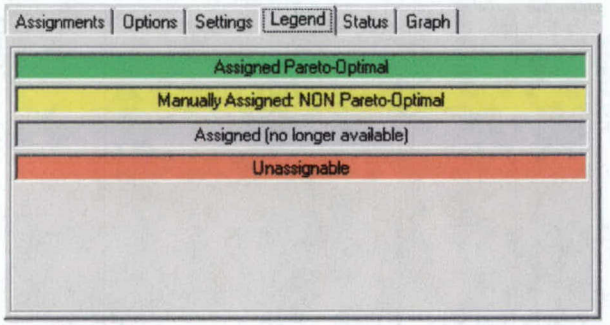
Each check box indicates a column that will be included in the Matching Table, and a graph that will be included in the choices of graphs in the Graph Sub-tab



Settings Tab

Settings

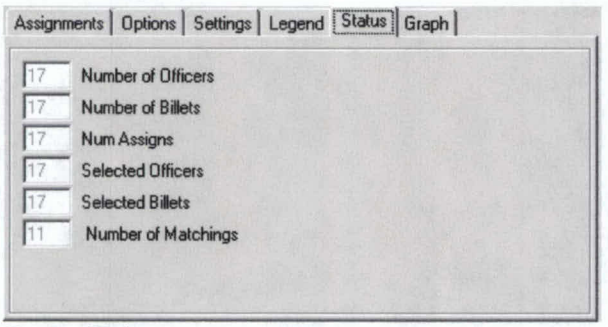
- Up Ranks - Number of ranks up to allow when executing the Reset Preferences button
- Down Ranks - Number of ranks down to allow
- Force Job Change - Limits eligibility to jobs that are not the current job.
- Months per Tour - Months to add to the transfer date when an assignment is confirmed.
- Max Gap - Maximum gap to allow for Reset Preferences
- Max Overlap - Maximum overlap to allow for Reset Preferences



Legend Tab

Legend

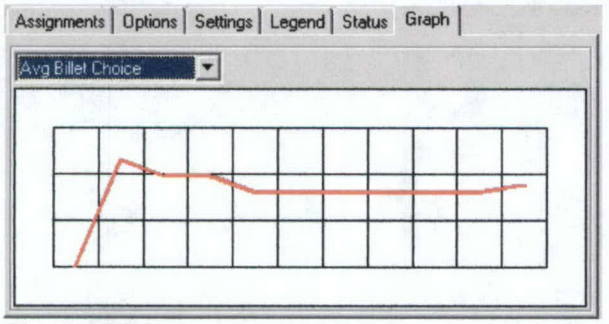
Defines colors assigned to Officers and Billets when the Show Colors toggle is on.



Status Tab

Status

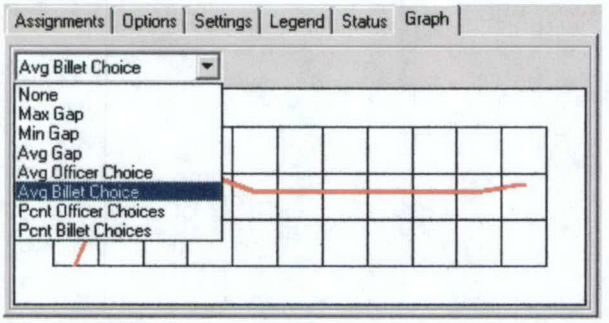
Status display showing current totals.



Graph Tab

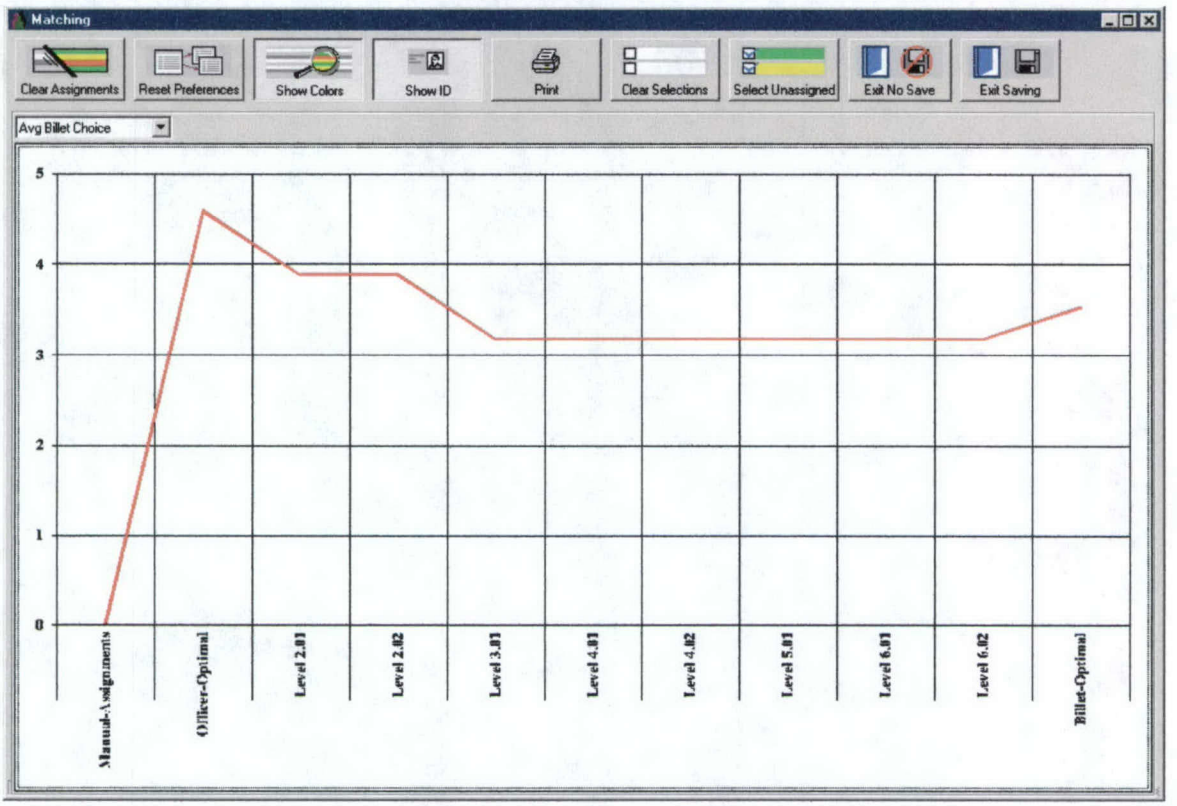
Graph

Displays a graph for each data column in the Matching Table. To display a specific graph, select it from the list box at top. Double click on the graph to see an expanded version which includes axis labels. The X-axis of the graph are the matching slates. The Y-axis is determined by which graph is selected in the list box.



Graph Selection

Window 7



When the user double clicks on a graph in the Graph sub-tab, that graph expands to fill the window and show axis labels.

Order of Program Usage:

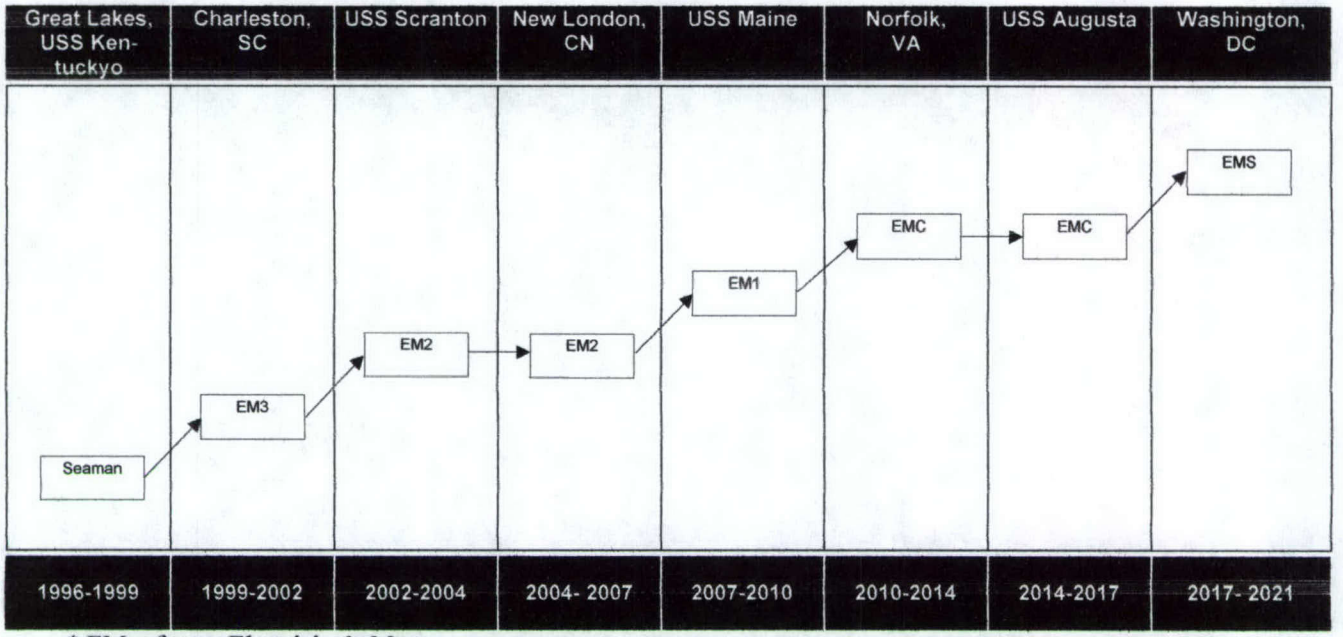
The user goes through a number of steps when using the Detailer program:

1. Define Officer database entries.
2. Define Billet database entries.
3. Order entries into a general preference order.
4. Set fields that define the current assignments.
5. Set fields that define the next transfer date.
6. Go to matching screen.
7. Verify eligibility as defined in each preference list.
8. Set any individual preferences in preference lists.
9. Make manual assignments for assignments that are certain and clearly required.
10. Perform two-sided match.
11. If there are multiple matchings, select the most preferred matching.
12. Confirm assignments.

THE SECOND DELIVERABLE: ENLISTED CAREER COUNSELING

Sailors generally know who their detailer is and they probably start thinking about their next assignment shortly after they arrive at their current job. There is a good deal to think about: the ship or station, the particular job they will be doing, where the job is, chances for promotion, connections with family or the spouse's family, connections with other sailors, and much else. As his rotation date approaches, concerns about his next assignment intensify. The Navy operates a web-based service that informs the sailor about available jobs and allows him to indicate his top five preferences. Unfortunately, this service, called JASS, does not indicate which jobs a sailor is eligible for. Hence, it is quite possible for a sailor to express a preference for a job he cannot have, because he is not qualified for it. The Navy, however, also provides career counselors. Eligibility is only one of the issues where a counselor can help. The sailor can usually benefit from more information about available billets. Most of all, however, the sailor needs help in expressing his preferences. The only "lever" that a sailor has are his preferences and he wants to use that lever wisely. To do that, he needs to know what his chances are of getting a job if he expresses a preference for it. He needs to know not just about jobs for the next tour but about career pathways, how one job leads or does not lead to the next, how his long-term career ambitions might best be fulfilled. It is at this point that software enters the picture. Career counseling would benefit from software that indicated eligibility as well as availability and, further, that indicated how a sailor's chances of getting a job varied with his expressed preferences. Our second deliverable is designed to meet this need conceptually, to indicate how such software might be developed, how it would work.

The first requirement of software intended to facilitate career management or counseling is a good user interface. A sailor needs to see the possible career paths he might take; a verbal description won't do. He needs to see the effect of a decision he makes now on what his career path might look like in five or ten years. The figure at the bottom of this page is taken (slightly modified) from a book on military careers originally published by the Department of Defense [America's Top Military Careers, n.d.]. It seems to us a good place to start. It is organized horizontally by tour and vertically by paygrade (also indexed by rate and job specialty). It also manages to convey calendar year and station. On the other hand, it needs development. It works better retrospectively than prospectively. There is only one past but the future is multiform. Somehow the figure needs to be modified so that it reflects this fact and allows a sailor to see the different possibilities ahead, a scrollable display perhaps or additional screens that could be



* EM refers to Electrician's Mate

opened up to display alternative possibilities. There could also be additional bars at the top or bottom giving further information about a sailor's situation on a given tour.

By itself, of course, a good user interface will not suffice. A sailor also needs information. Specifically, he needs probability information. Suppose a sailor is an Electrician's Mate, a submariner, and just finishing his second tour, as above. He needs to know which jobs he is eligible for, but also how likely he is to get a job if he indicates a preference for it. The sailor may have a clear idea about what he wants his situation to be when he finishes 20 years of service. If so, he will want to know the various routes to that goal and how probable (or improbable) they are.

Historical data are one way to obtain probability information. In the last few years other sailors have been in the same general situation as the Electrician's Mate in our example, and some of those sailors have been assigned to the kind of situation which the sailor is considering. The proportion who are so assigned can be taken as a rough indication of the sailor's probability of getting his preference if he asks for it. The same approach can be taken to future tours. If the sailor gets the job he wants and if he performs well (obtains the required promotions, qualifications, and fitness reports), what is the probability of his being assigned as he would like in the next several tours? The proportion of sailors who have actually followed a given pathway is a possible answer.

There are problems, however. Clean historical data are notoriously difficult to obtain. The records are not always filled out correctly, sometimes relevant items are missing altogether. Even finding a record can be a problem. Furthermore, historical data are necessarily out of date.

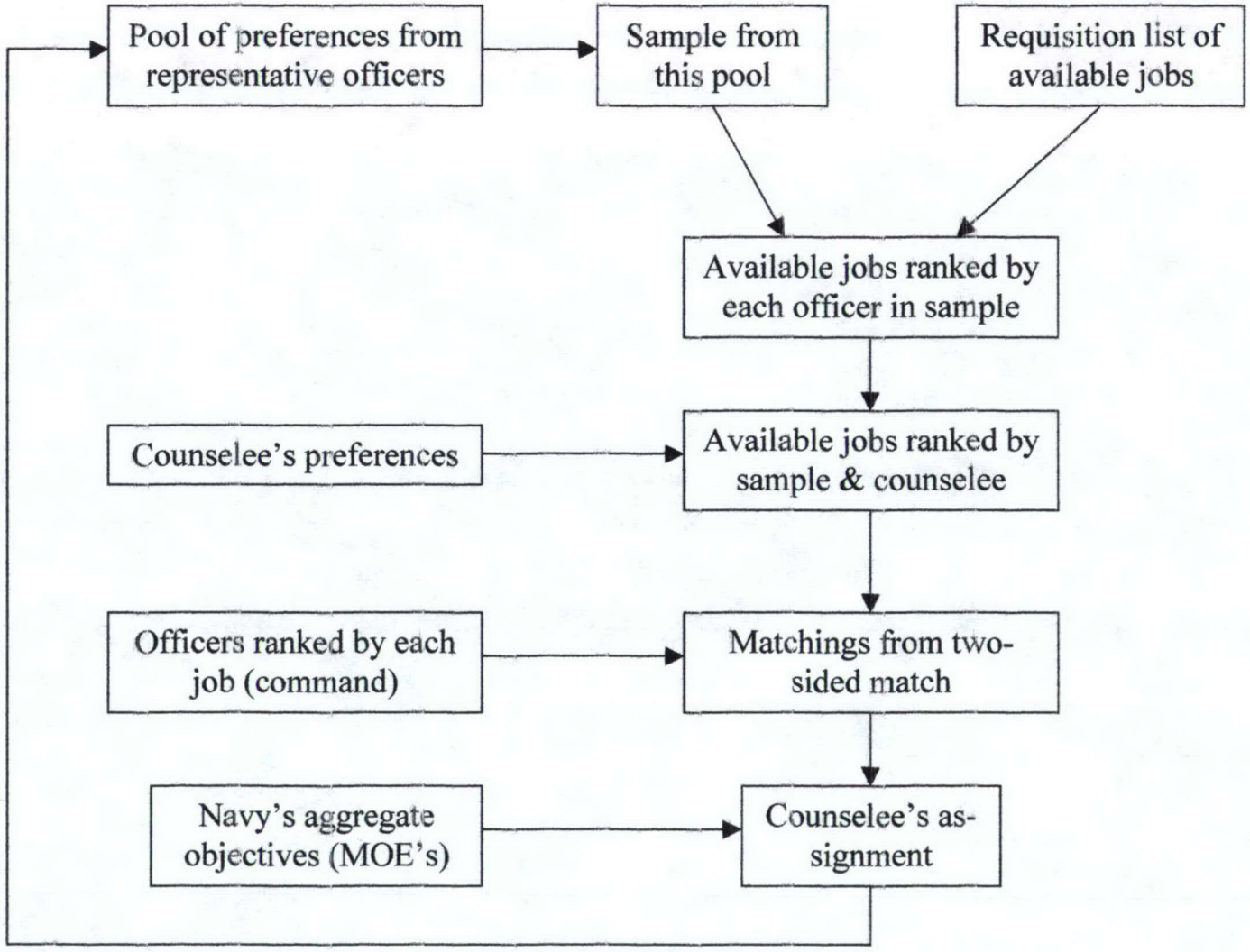
The situation confronting a sailor ten or even five years ago may differ in important respects from the one facing a sailor in the same rate and rating today. The civilian economic situation may be different, prospects for war or peace may be different. Most importantly, historical data do not contain preferences. The historical record can usually, or at least often, tell us where in fact a sailor was next assigned. What it does not tell us is where he wanted to be assigned.

For these reasons we prefer an approach based on representative samples of current sailors and two-sided matching. The diagram on the next page (26) outlines the approach, beginning with the "pool of preferences from representative sailors" at the upper left. In principle, there would be a separate pool for each combination of rate and rating. In practice, however, it may be that the preferences of some rates and ratings are sufficiently similar that a single pool will serve for several combinations of rate and rating.

A second point concerns the preferences themselves. Pages 27-29 contain a duty preference form that has been collected by the Navy (but little used) for many years. Note that the form does not ask the sailor to indicate his preferences for particular billets but, rather, for kinds of preferences. What are his preferred locations for sea duty, shore duty, and overseas duty? What are his school preferences? What are his career intentions? This form is not usable as it stands for generating assignment probabilities. It needs to be expanded and quantified. However, once that is done, it is a simple matter to devise a scheme for rating a particular billet according to a given sailor's preferences. If the sailor's top choice is an overseas billet in Naples, then a billet in Naples will get top marks. Billets elsewhere will be rated according to the sailor's preferences among possibilities other than Naples. Preferences in different categories, for example, location, kind of billet, chances for promotion, etc. can be combined by a variety of schemes. One such scheme, based on the scoring metric used in the Wilcoxon matched-pairs test for signed ranks, is described in the appendix to Appendix A. The result is a score reflecting the sailor's preferences for each available billet.

Moving to the right from the upper left-hand corner of the diagram on page 26 a sample, numbering as many sailors as there are jobs on the current requisition list, is drawn from the pool of representative sailors. The pool is constructed always to be larger than a current requisition list. Each sailor's preferences are then applied to produce a list of "available jobs ranked by each sailor in the sample." Moving down and to the left, the sailor-counselee's tentative preferences are appended to those for the sample and the augmented preferences (sample plus counselee) applied to the available jobs.

Procedure for Generating Assignment Probabilities



BUPERS ACCESS Duty Preferences

BUPERSAccess Online

Preference Section

Rank in order of desirability (1, 2, 3)

0 Sea 0 Overseas 0 Shore (Note: Selections must have different numbers or your record will not be processed)

Indicate whether LOCATION (L) or TYPE duty (T) is more important.

L Sea L Overseas L Shore

For locations, first click on the 'Choose Locations' button. In the new window, select ALL the locations you would like to add to your list box. After closing that window, you may choose your list box items using the drop-down boxes.

[redacted]

SEA

	Location	Duty / Activity Type
1st Choice		
2nd Choice		
3rd Choice		

OVERSEAS

	Location	Duty / Activity Type
1st Choice		
2nd Choice		
3rd Choice		

SHORE

	Location	Duty / Activity Type
1st Choice		
2nd Choice		
3rd Choice		

School Preferences and Duty Extensions

School Preferences:

School Preferences:
(Write in school or classification code (i.e., IT "C", 2735, or ref. CANTRAC)

Volunteer: Choose from below

Duty willing to extend for:

Duty type **Location**

[redacted]

Career Intentions and Deployment Codes

Last Deployment:

When returned: Month / Year **Length:** Months **Where:** Not Applicable

Career Intentions:

Codes: Select One

- ○ Reenlist at EAOS
- ○ Ext onboard Present Duty Station
- ○ Extension at EAOS
- ○ Uncertain
- ○ Discharge at EAOS
- ○ Fleet Reserve/Retire

Months desired for Extension or Reenlistment. None

Personal Considerations/ Family Items

Family Member Information:

Number by Age Group

STATUS: Single

	Ages 0-4	Ages 5-11	Ages 12+
M	0	0	0
F	0	0	0

Number Family Members at other location: 0

Primary Location

Other Location

Military Spouse:

If Navy, enter SSN - otherwise enter Branch of Service

If separated, indicate M for married. For working spouse, indicate W and include details in the REMARKS section. For military spouse, include rank/rate and current duty station. If Navy, indicate SSN in space provided or it other than Navy, indicate branch of service. Indicate location of family members(s) and the number of children in the categories of age. Also, provide location information, if applicable, of family members(s) on page 2 residing elsewhere.

Quarters Information:

Present Duty Station

Types: N/A

Own ○ **Rent** ○

Other Area

Types: N/A

Own ○ **Rent** ○

Location

Indicate present duty station quarters type and whether you own or rent. If you own or rent in another area, indicate this in the area labeled "Other Area".

Household Effects:

Present duty station weight: (in thousands of pounds)

Other location weight: (in thousands of pounds)

Location

If known, indicate the weight of household goods in thousands of pounds. If any of your household effects are stored elsewhere, indicate the weight and location.

Note: Household goods less than 1000 pounds, but greater than 300 pounds, should be indicated by "01" for 1000 pounds.

Contact Information for Detailers:

1st E-mail: (limited to 39 characters)

steven.clemens@persnet.navy.mil

DSN Phone:

United States - 882 - 2137 ext.

2 nd E-mail:

Commercial Phone:

9018742137

Update Personal Info. ☑

Remarks: (limited to 80 characters; any excess will not be submitted)

List any additional information which may be useful in determining your next duty assignment, such as, expected date of delivery if wife is pregnant; handicapped dependent, and areas where treatment facilities are known to exist; family limitation, EFM; etc. NENEP, NEDEP, BOOST, STAR, SCORE, WARRANT OFFICER, LDO, PEP, GUARD etc. List any skills, other than NEC's in which you are qualified. Personnel of the following rating should consult Chapter 2 of the TRANSMAN for additional instructions: EO, CM, SW, UT, MU.

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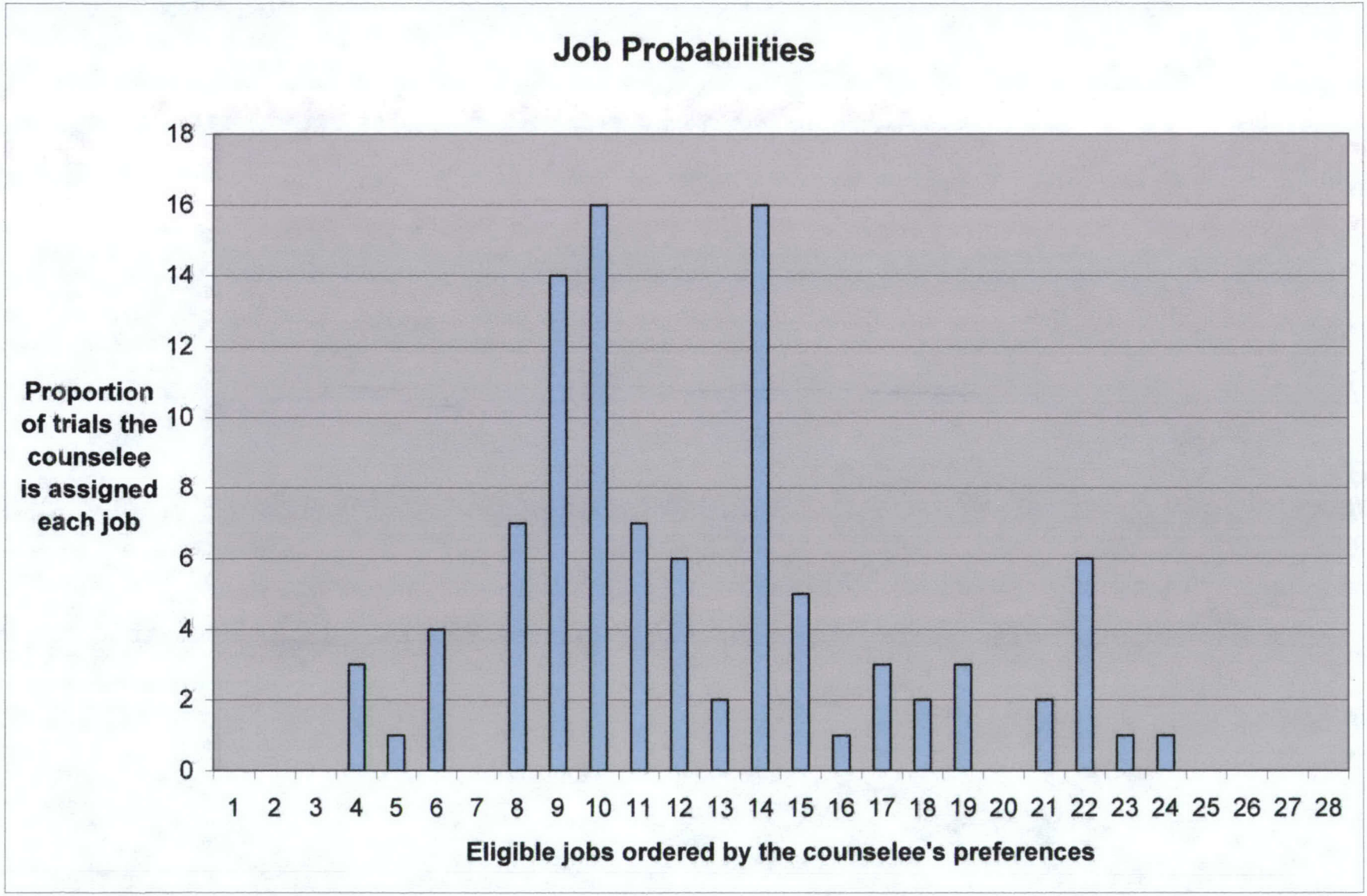
A similar process is then used to rank each sailor in the sample and the counselee according to the command preferences. At present, these preferences are taken to be disaggregated Navy preferences: NEC reutilization, moving costs, gap times. A more fully developed process would extend this list to include information about the sailor's past performance and career intentions, differentiated by individual commands and billets. The Wilcoxon or some other scheme is then used to obtain rankings of each sailor by each command.

The next step is the two-sided match (the second box up from the bottom on the right). The match will list all possible stable matchings of sailors with jobs. Ordinarily there will be many such matchings. These matchings will all be stable, but they will not all be equivalent from the Navy's point of view. In some the number of sailors who need further training to be NEC-qualified for the job assigned them is too high. In others the total moving cost may be too high. In still others gap times may be unacceptable. An algorithm that imposes these various constraints and evaluates each matching for conformity to Navy targets and requirements is easily devised, and a single best matching selected. In this matching the sailor-counselee is assigned to a particular billet.

This entire process is then repeated (the arrow that sweeps around and back to the upper left-hand corner). A new sample is selected from the pool of representative sailors, jobs and sailors ranked, the two-sided match is run, and Navy targets and requirements imposed. The upshot is a second assignment for the sailor-counselee. This process of resampling and determination of assignments for the sailor-counselee is repeated many times.

The sailor-counselee in the table on page 31 has expressed preferences which make it very unlikely that he will get any of his top three choices, and the likelihood of his next four choices (4-7) is not much better. The reason in all probability is that he has stated preferences which put him in competition with many other sailors, some of whom are better qualified than he is. On the other hand, the larger proportions for choices 8-11 may be based on preferences which, if more heavily weighted, would make these jobs serious likelihoods. These possibilities can then be explored by the counselor and counselee together. The process continues until the chances are good that the sailor will get a job he wants or, at least, recognizes as the best he can expect to get.

This approach offers the advantage of currency in both sailor and command preferences. The goals and requirements of the Navy are also current. Its principal limitation concerns future tours of duty. A sailor may want to know what his options will be two or more tours ahead. If


Job Probabilities
Proportion of trials the counselee is assigned each job
0
2
4
6
8
10
12
14
16
18
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Eligible jobs ordered by the counselee's preferences

the sailor performs well in his next tour (obtains the required promotions, qualifications, and fitness reports), his situation at the end of the next tour can be anticipated. His prospects for the second tour ahead can then be assessed by the same approach as was used to assess the first.

Extending into the future this way involves highly questionable assumptions. At the end of the next tour the sailor's situation will probably be different; he may, for example, have been promoted to a higher paygrade. Presumably, however, there will be a pool of representative sailors for that paygrade too. A much more serious difficulty is that in a period of three or four years the preference structures may change. Sailors in general may want somewhat different things or weight what they want somewhat differently. In addition, the list of available jobs three or four years from now may also be different. More importantly, the kinds of available jobs may change. Job structure may change.

In short, one can use the approach we have described to project into the future only on the assumption that preferences and job structures remain the same as they are now. In the short-term, perhaps two or even three tours, this assumption may not be greatly in error. For longer periods of time, however, great caution should be exercised.

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Appendix A

Development of an MPT Management System: First Progress Report (ONR Contract No. N00014-00-C-0270)

Isoperformance, Inc.
Mechanicsburg, PA
December 12, 2000

Introduction.

The first objective of our Phase II proposal was to develop a stand-alone software package (Package 1) "for use in personnel situations characterized by many jobs, small quotas (often just one), and many constraints on who can be assigned where, for example, the costs of moving a sailor to a new assignment, marital status, age, previous assignments etc." Enlisted detailing was specified as prototypical of the personnel situations we had in mind. We also said that the proposed software would be "focussed primarily on constraint satisfaction." After visiting Millington at the very start of the contract, meeting with Tony Benson and Steve Clemens, and learning as much as we could in two days about the detailing process and about the Assignment Policy Management System (APMS), that focus changed. Constraint satisfaction still plays a role in Package 1 but that role is secondary. The primary focus now is on the sailor-job match—more precisely, on providing tools to help the detailers make that match.

We were very impressed by the detailing process as it is currently carried out—by its focus on finding the best job for the sailor and for the Navy, by its personal character (that most sailors know who their detailers are, that sailor and detailer actually talk with one another and sometimes strike bargains, that no detailer wants to "slam" anyone if it can possibly be avoided), and by the detailers themselves (their knowledge of and concern for the sailors, their understanding of what each job requires, their standing in their communities). This impression was reinforced by John Burlage's article in the *Navy Times* of November 20, 2000, about the Detailer Communications Initiative. The Navy's plan to have detailers take the initiative in contacting sailors and sometimes to visit them in the fleet reinforces precisely those aspects of the detailing process that impressed us so favorably on our visit to Millington.

We drew five major conclusions from our visit. First, any software we write should be aimed at assisting the detailer to make the sailor-job match. The software should help to assemble and assess information about the fit between sailor and job, but assignments should be made by the detailer. Second, the software should have a minimum of batch work; whatever information or shortcuts it provides should be aimed primarily at an individual sailor and the jobs for which he or she is eligible. Third, the software should be such that the detailer maintains intellectual contact with its operations when using it. It is especially unhelpful for the software to break off contact in order to carry out technically obscure calculations and then to present a slate of "optimal" assignments. Fourth, the software should be interactive, that is, such that a detailer can exercise it easily and quickly. An obvious corollary of this fourth conclusion is that no computation should take more than one or two seconds to carry out. Fifth and finally, nothing we do should aggravate the already difficult situation that detailers face in tying their existing software tools together. Information should flow to and from our software with the least possible effort from the detailer.

Much of the APMS software would be invaluable for our purposes. It isn't necessary to incorporate APMS modules as they stand; but the analysis of Navy standards and operations that has been coded into APMS modules would be very helpful to us and would save a great deal of time. For example, the eligibility module in APMS determines which jobs an individual sailor can have, which jobs he or she is eligible for. No software intended to assist detailers in making the sailor-job match can do without such a module. The Measures of Effectiveness (MoE) module spells out how some 40-odd measures of effectiveness, for example, JASS preference and NEC reutilization, are to be coded. If not incorporated from APMS, this work will have to be redone. Still another module, Monitor, provides a given detailer with a running record of how his or her assignments to date square with Navy goals and expectations. This module would also be helpful, as would whatever interface information exists in the APMS Transfer module.

APMS is designed to determine a slate of assignments that maximizes specified meas-ures of effectiveness. This goal is not the same as ours (helping the detailer to rank order the jobs for which a sailor is eligible but leaving it up to the detailer to make the assignments).

In the next section we consider basic principles involved in the sailor-job match and their implications for assignment.

The section after that develops Package 1 as we now envision it, and the last section describes our current status vis-à-vis programming, outstanding obstacles, and plans for the next four months.

Interpersonal comparison of utilities and Pareto optimality

In his *Navy Times* article Burlage writes: "JASS remains at the heart of the Navy's detailing process, after three years of work to make it the premier method for matching sailors and commands requiring their specific talents." Whatever other measures of effectiveness are also involved in matching sailors to jobs, the sailor's preference (JASS) seems certain to be involved. So let's start with JASS.

Our understanding is that JASS allows a sailor to apply for as many as five jobs and to rank them in order of preference. If sailor preference is the only measure of effectiveness, the job of matching sailor to job is simplicity itself. The detailer simply assigns the sailor to his most preferred job.

Suppose, however, that two sailors both want the same job (and sailor preference is still our only measure of effectiveness). What then? If sailor preference meets the requirements of an interval scale[2] and if interpersonal comparison of utilities is allowed, this question can be answered. Assigning either sailor to the one job that both want yields a "preference value" of some magnitude. The detailer assigns that sailor whose assignment yields the larger value. If 10 sailors are to be assigned, the detailer assigns all 10 "as nearly as possible" to their preferred jobs and sums the preference value for all 10 assignments. Because he can't be quite sure that the set of assignments he has chosen really is "as near as possible" to the sailors' preferred jobs, he tries another set of 10 assignments and sums its 10 preference values. He continues in this fashion until every set of 10 assignments that could possibly yield the largest summed preference value has been tried. When he has finished, one set of assignments or perhaps several such sets have a

[2] This terminology was introduced a half century ago by Stevens (1951, 1961) and has been widely adopted in the behavioral and social sciences. A *nominal* scale is one in which numbers are used as names as, for example, the numbers on football players' shirts. An *ordinal* scale is a ranking, like order of preference. One can say that one item or option is more or less than another (or equal) but no testable or operational significance attaches to the difference between them. In an interval scale the differences between points or options can be compared but the zero point is arbitrary. Hence, it is "meaningless" to say that one item is twice as large as another. In a *ratio* scale the zero point is not arbitrary and all the arithmetic operations are "legitimate."

summed preference value as large as or larger than any other set. That set (or sets) is then the (or an) optimal assignment set. In essence, this is the procedure followed by APMS.[3]

And there is nothing the matter with it, provided the assumptions on which it rests are met. The problem is, to put it conservatively, that these assumptions are highly controversial and not generally accepted in the discipline where they have been most studied (economics). An order of preference constitutes an ordinal, not an interval scale. The first-ranked job is preferred to the second, which, in its turn, is preferred to the third; but nothing at all is asserted about the differences between the ranks. Even if this objection were somehow to be overcome, it would be another and even more controversial step to compare differences between ranks for one individual with differences between ranks for another. The problem with interpersonal comparison is that each individual has his own implicit scale of values. Hence, interpersonal comparison mixes up apples and oranges; we don't know the scale that either individual is using. "The viewpoint will be taken here," wrote Arrow (1951), in his classic work on social choice and individual values, "that interpersonal comparison of utilities has no meaning...It requires a definite value judgment not derivable from individual sensations to make the utilities of different individuals dimensionally compatible and still a further value judgment to aggregate them according to any particular mathematical formula. If we look away from the mathematical aspects of the matter, it seems to make no sense to add the utility of one individual, a psychic magnitude in his mind, with the utility of another individual. Even Bentham had his doubts on this point."

Is there anything then that can be said about how good or bad a slate of assignments is? Fortunately, there is. Suppose one arranges the individuals in an arbitrary order and assigns one after the other to his or her first job choice. Where the first choice has already been filled, the individual is assigned to his or her second job choice. If that job has also been filled, the individual is assigned to his or her third choice; and so on. A slate of assignments so obtained is "Pareto optimal," that is, no individual can be assigned to a better job without reassigning some

[3] Because we have not yet been able to obtain either its documentation or its code, we cannot be certain as to what exactly APMS does. Given, however, what we do know, we are fairly sure that it runs a sequential (or preemptive) linear program. APMS requires the user to specify and rank up to five measures of effectiveness for the program to use in assigning sailors to jobs. Goals are then set for each measure and organized into levels, perhaps with weights for each one (but perhaps not). It appears that the levels correspond to the five ranked measures of effectiveness. If so, the program runs a nonsequential program using the top ranked measure only. If the solution is unique, the resulting slate of assignments is final. If there are ties, the second ranked measure is used to decide among them. If there are still ties, the third ranked measure is invoked, and so on.

other individual to a worse one.[4] Any such set is "better" than a set which it dominates, that is, a set in which each individual is assigned at best the same choice as in the Pareto optimal set and some individuals are assigned less preferred jobs. Consider three individuals and five jobs (A,B,C,D,E). All three individuals prefer A to B, B to C, and all three to D or E. In one assignment set the three individuals are assigned A, B, C in that order and in the other A, D, C. The first set dominates the second, because the second individual does worse in the second set than in the first, while the first and third individuals do the same. The first set is Pareto optimal, because there is no way to improve any individual's assignment without worsening another's. The second set is not Pareto optimal because both the second and third individuals can be assigned more preferred jobs without having to reassign the first individual to a less preferred job. The second individual could be assigned to C and the third to B. Both would benefit, and A would not be disturbed.[5]

Pareto optimal sets have strong properties, but uniqueness is not one of them. Typically, there are many Pareto optimal sets. A decision among these sets must then be made on some other basis than order of preference. In our program this other basis is one or another of the group or aggregate measures of effect, for example, NEC reutilization rate or average cost of moving to the new assignment. The detailer selects an assignment set that, for example, improves NEC reutilization rate or reduces average cost of moving. The group measure used to make such a selection may or may not have been used in matching sailors with jobs.

Detailers often have information that no computer program can be expected to capture. They know the community, ships, stations, and jobs. They have usually talked with the sailor and may have visited with him or her in the fleet. They may even have bargained with the sailor over reenlistment and the sailor's next assignment. The role of our software is to assist in the assignment process (by allowing the detailer to prioritize rollers or jobs, by organizing information for

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[4] Following such a procedure, it may happen that one or more individuals cannot be placed at all. Suppose, for example, that an individual is eligible for only one job. If that one job happens to be someone else's best job and the other individual is placed first, then the individual who is uniquely eligible for the job cannot be placed at all. Our software takes this possibility into account.

[5] Pareto optimality is discussed in almost any book or article on price theory or social choice. The idea was introduced by Pareto in his *Manuel d'économie politique* (Pareto, 1909). A translation of the relevant passages can be found in Page (1968).

the sailor-job match, by identifying unassignable individuals, or checking on Pareto optimality) and not to interfere with or disrupt continuous detailer control but positively to facilitate it.[6]

Package 1 as now envisioned

Ordering variables, matching criteria, and aggregate measures. In order for a variable to be helpful in matching sailors with jobs it must vary in both respects. An item like whether or not a sailor has been recommended for reenlistment varies only by sailor. It does not help in matching because it takes the same value for all jobs. Similarly, the importance of a job to the Navy varies only with the job. It takes the same value for all sailors and, hence, is no more helpful in matching sailor and job than whether or not the sailor has been recommended for reenlistment. We call variables that vary only with sailors or only with jobs *ordering variables*.

The initial screen in Package 1 presents the current rollers in one window and available jobs in another. Ordering variables follow in columns after a sailor's name or a job descriptor. The default ordering variable for sailors will be Projected Rotation Date; the more imminent the date the higher in the order of presentation. The default ordering variable for jobs will be importance to the Navy as indicated by Requisition Priority (at least, we think we saw such a variable when we were in Millington). By clicking on the head of a column the detailer can resort the jobs or sailors according to any ordering variable he or she chooses. The function of the ordering variables is to allow detailers to prioritize their own decisions. All assignment decisions are not on an equal footing. A detailer may have agreed to give some sailors their first choice in return for their reenlist-ment. It is more urgent to assign sailors whose Projected Rotation Date is only a few weeks away than to assign sailors whose Projected Rotation Date is still several months into the future. Similar considerations apply to Requisition Priority.

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[6] The multiple job assignment problem has received surprisingly little attention in the literature. More than 40 years ago, Brogden (1946, 1955, 1951, 1959) and Horst (1954, 1955) showed, using interval measures of effectiveness, that a unique optimal assignment set could be obtained by assigning each individual to his or her "best" job, where "best" was defined in terms of predicted performance. Brogden and HMore recently, a group of researchers centered around the Army Research Institute (Johnson & Zeidner, 1991; Rumsey, Walker, & Harris, 1994; Statman, 1993; Zeidner & Johnson, 1991a,i 1991b; Zeidner, Johnson, & Scholarios, 1997), using greatly relaxed assumptions and numerical methods, have reexamined Brogden's and Horst's work and confirmed the importance of assignment, even under approximately real-world conditions (Jones, 2000).

It should be noted that both the early and more recent investigators underscore the primacy of the individual-job match. To the extent that individuals and jobs can be well matched, the resulting assignment set will be optimal. In short, even when an optimal assignment slate is the ultimate objective, it can only be achieved by optimal matching of sailors to jobs.

We call variables which vary by both sailors and jobs *matching criteria*. Examples are NEC reutilization (Is the sailor already qualified for this enlisted classification?), the cost of moving a sailor to a new location, and, of course, JASS preference. These are the variables that matter in making the sailor-job match. Detailers almost always want to assign a sailor where he or she wants to be assigned. The cost of doing so is also a consideration, and part of that cost may be whether or not the sailor is already trained or experienced at that particular kind of job.

Aggregate measures are often simply aggregate matching criteria. For example, the detailer may want to know how many sailors in an assignment slate are getting their most preferred job or the proportion the detailer has assigned to their most preferred job in the last year. Aggregate measures apply to groups or series of sailors, not individuals. Their function lies in the selection for implementation of one Pareto optimal slate rather than another.

Selecting and ranking sailors or jobs. Also on the Package's initial screen is a window allowing the detailer to specify and rank any required number of matching criteria.[7] These are the considerations that the detailer wishes to take into account in ranking a sailor or sailors for a specified job. A detailer who wants to think more closely about a particular sailor clicks on the sailor's name and the program presents all the jobs for which that sailor is eligible together with the matching criteria for each job. If the sailor is eligible for four jobs and the detailer has specified JASS preference, NEC reutilization, and moving cost as matching criteria, the program will present the values that each criterion takes for each job.

A detailer who wants to think more closely about a particular job clicks on the job's descriptor and the program presents all the sailors who are eligible for that job together with the matching criteria for each sailor. A detailer, let us say, has settled on the best job for a particular sailor; but there may be other sailors who have a better claim on that job than this particular sailor. If so, the detailer may well want to know who they are and, perhaps, to consider them in the same panel as the sailor first in question, especially if the job has a high Requisition Priority. In some instances, finding the best sailor for the job may take precedence over finding the best job for a sailor.

In both cases, our package presupposes that the APMS Eligibility module or its equivalent is included. If we have only the APMS documentation, we can, we believe, write an effective

[7] Our present intention is to allow for up to five criteria, but we need counsel on this point.

demonstration program, but an operational program requires that we have an eligibility module in place.

When a sailor or job is selected, the program not only presents the jobs for that sailor or sailors for that job, it presents them in an order based on the matching criteria specified and ranked by the detailer. This ranking is, of course, tentative and incomplete. Its function is to provide a starting point for the detailer and to indicate how the matching criteria alone, not yet placed in an informational and judgmental context supplied by the detailer, seems to rank the sailors or jobs. The detailer can and, we expect, usually will make changes in the rankings provisionally provided by the program.

The program uses a multivariate extension of a metric used in Wilcoxon's matched-pairs signed ranks test (Siegel, 1956) to make its preliminary ranking of job or sailors. The Wilcoxon extension provides an average of sorts of the rankings made by the individual matching criteria. For details, see Appendix A. It needs only to be pointed out here that the Wilcoxon ranking (or that made by the detailer) is ordinal in scale, because JASS preference is almost always one of the matching criteria and as long as any one of the matching criteria is ordinal then any scale derived from them, supplemented or not by detailer information and judgment, is also ordinal. Even if JASS weren't one of the matching criteria, the final scale would still be only ordinal because of the unavoidably judgmental nature of combining multiple criteria, not to mention the detailer's input.

Unassignable sailors and separable subsets. When a detailer has ranked the jobs for a series of sailors, the next step is to decide which sailors should be assigned to which jobs. If only a few sailors are to be assigned, the problem is sufficiently simple as to require few, if any, aids from the program. In general, a detailer is well advised not to consider more than 10 sailors for assignment at the same time. The tangle among possible assignments becomes so dense that intellectual contact has to be broken off while computational aids do their work; and the aids take more than one or two seconds to run. For panels of 10 or so sailors, however, the program provides a couple of aids that are both quick to run and easy to understand.

A detailer usually wants to place all the sailors in a panel in one of their high ranking jobs, say, one of the top three. Depending on the eligibility matrix, however, it may not be possible. If, for any subset of jobs, the number of sailors whose top three jobs all lie in the subset is larger than the number of jobs in the subset, then it isn't possible to place all the sailors. Either one or

more will have to be left unassigned for the time being or the goal of placing all sailors in one or another of their top three jobs will have to be relaxed. Consider the five job subset A-E. If these five jobs include the top three for as many as six sailors, then one of those sailors is unassignable. The detailer can take his or her pick of the six sailors but all six cannot be assigned.

This information is worth a detailer's knowing up front, before starting to puzzle through the panel. The program provides an algorithm that allows the detailer to find out in less than a second if there are any such subsets and, if so, which subsets they are and which sailors they involve.[8] The existence of unassignable sailors is not necessarily a disaster. If time to Projected Rotation Date is not too short, there will be another requisition list in a month. Perhaps the panel includes a sailor whom the detailer would like to think more about anyway. Or, it may include a sailor whose fourth best job is also pretty good—or a sailor who, with a little training, would be just fine for some other job. There are many possibilities, but it helps to know at the beginning if they need to be considered. Of course, if the algorithm indicates that there are no overpopulated subsets, it helps to know that everyone can be assigned a top-three job.

A second aid is called *separable sets*. Suppose again that the detailer would like to assign all sailors to one of their top three jobs. Consider a subset of, say, five jobs (A-E) such that no one with a top-three job in the subset has another top-three job outside it. An individual either has all three top-three jobs in A-E or none. Such a subset is completely disjunct from its complement (all other jobs for which any member of the panel is eligible). Disjunction occurs more often than might be thought and, when it does, it greatly simplifies the detailer's assignment problems, because the disjunct subsets can be considered completely independently of one another. Instead of a panel with 10 sailors, the detailer may have three panels, one with five sailors, another with two, and a third with three. The advantage here is not computational time but focus. Three smaller panels are easier for a detailer to think about than one much larger one. The detailer can concentrate on a few sailors and jobs without fear of missing relevant others.

This second aid is also represented by an algorithm and it too runs in less than a second for a 10-job panel.

Selecting a Pareto-optimal panel. It is unlikely that a detailer will put together an assignment panel that is not Pareto optimal but, just in case, the program provides a check. A more likely

[8] This is the same algorithm as was programmed in Phase I of this contract. The original program took several minutes to run for 10 jobs. In Phase II running time has been reduced to less than a second.

hazard is that the average moving cost for the panel will be higher or the NEC reutilization rate lower than the detailer would like. Even when moving cost and NEC reutilization have been included among the matching criteria, the results for an assignment panel may diverge from Navy policy targets. On the second screen of Package 1 the detailer can scroll through a list of aggregate measures. Our recollection is that APMS describes and codes some 40-odd. By clicking on one of these measures the detailer can obtain the average or rate for the current panel. The detailer can also obtain the

rate or average for all assignments he or she has made since a specified date. In a panel of size 10 one does not expect all Navy targets to be satisfied. It is probably not possible. One can ask, however, whether the current sample converges on diverges from Navy targets, at least the most important ones. This much the detailer can determine by asking for aggregate measures.

If the current panel leads an aggregate measure away from a policy target, what can a detailer do about it? Suppose that the detailer's top three jobs for each of five sailors are:

	Job						
Sailor	A	B	C	D	E	Assignment	Reassignment
1	1	2			3	A	A
2	2	1			3	B	E
3	1	3			2	E	B
4	3	1	2			C	C
5	3	1		2		D	D

The detailer's assignments are indicated in the next to last column on the right. The panel is Pareto optimal. It turns out, however, that only sailor 1 is assigned to a job for which he is already NEC classified, and the Navy target is higher. The detailer notices that sailor 3, who is currently assigned to E for which he is not NEC classified, is NEC classified for his third best job (B). So the detailer reassigns sailor 3 to B instead of E. There is nothing "wrong" with such a reassignment. The detailer is simply reversing sailor 3's second and third best jobs. B is now sailor 3's second best job and E his third best job.

There is a problem, however. In the original assignment job B was assigned to sailor 2. So sailor 2 has also to be reassigned. His next best job after B (since his second best job, A, has been preempted by sailor 1) is E. So in this instance sailors 2 and 3 simply change assignments, and the NEC reutilization number for the panel is now two instead of one. However, giving sailor 2 his third best rather than his first best job may not be acceptable to the detailer. It is possible that sailor 2 is not even eligible for E. In either event, the detailer will have to consider reassigning sailor 2 to some other job than E. But reassigning sailor 2 elsewhere than to E may also present problems.

In short, reassigning one sailor in a panel may present a problem, and "fixing" that problem may entail further problems. Fixing those problems may entail yet further problems. Such a series of fixes can become seriously tangled. The program, therefore, not only allows the detailer to make a series of fixes (usually intended to improve some aggregate measure or measures) but also keeps track of them. They are all saved, and the detailer can scroll back through the panels and stop wherever he or she wishes to stop. It may be that the detailer will conclude that there is no better panel than the one with which he or she began.

Current status, outstanding obstacles, and plans for the next four months

The constraint satisfaction algorithm, as noted earlier, now runs in less than a second for a 10-sailor panel. The generalized Wilcoxon metric has also been programmed, as have two screens, one for selecting and ranking sailors and jobs, and the other for assignment and reassignment. The screens are still rather "empty" because we lack the APMS documentation. This lack is much the largest obstacle we currently face. Our hope is to obtain the documentation soon—Tony Cunningham e-mailed us that he had made a "command decision" to send the documentation to us. Within two months of receiving the documentation we believe we can make a preliminary but credible presentation to you, Tony Benson, and Steve Clemens. The purpose of the presentation would be to receive your comments, criticisms, and suggestions. We will then put the software through a revision and try again.

We would then like to make a presentation to Lt. Cmdr. John Heckman, coordinator for the Detailer Communications Initiative. Our hope is that with sufficient support we will before too long be able to obtain access to the APMS code. Once we have the code, we believe we can produce an operational program within six months.

After getting your response to this progress report, our first step will be to revisit Millington. At that time we would try also to visit with Steve Watson about RIDE. After enlisted detailing, we hope to tackle recruitment and assignment to A school.

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Appendix A

The Wilcoxon matched-pairs signed-ranks test is a nonparametric homologue of a paired (or correlated) *t* test. The typical dataset consists of *n* subjects each of whom has two scores, for example, before and after. A representative dataset might look like:

Subject	X	Y	Δ	Rank of Δ
1	82	63	+19	4
2	69	42	+27	5
3	73	74	-1	-1
4	43	37	+6	2
5	51	58	-7	-3

The difference score (Δ) equals (X-Y) and the differences are then ranked by absolute value and given the sign of the difference. The present usage is not, of course, to test a hypothesis; our

only interest is the metric the Wilcoxon test uses to assess the relative magnitudes of X and Y. This metric (T) equals the sum of the positive ranks or the sum of the negative rank, whichever is smaller. For our purposes, it is best to sum both the positive and the negative ranks.

To adapt the Wilcoxon metric to our purposes, suppose we have one sailor, two jobs, A and B, and five ranked matching criteria (MC). The problem is to develop a rough measure of which job is better and which worse, using all five criteria. A representative dataset might look like:

Matching Criterion	Ranked by Importance	Job A	Job B	Signed Rank
JASS	5	2	1	+5
Moving Cost	4	1	2	-4
NEC Reutilization.	3	2	1	+3
Fourth Criterion	2	1	2	-2
Fifth Criterion	1	2	1	+1

The format is basically the same as in the usual usage, with two differences. The sign of the difference for a given criterion (MC) depends on which job is better for that sailor on that MC, where "2" indicates the better job. In the first row, the "2" for A means that the sailor prefers job A to job B. The "2" for Moving Cost means that moving costs are lower for job B than for job A. The rank of the difference for a given MC is given by the detailer. If he or she feels that two jobs are equal in importance, the detailer assigns both jobs the average of what would have been their untied ranks. In the example, the detailer has specified JASS preference as the most important difference, Moving Cost the second most important, and so on.

The Wilcoxon metric is then calculated as it usually is, by summing the positive and negative ranks. In the example, the two sums are 9 and 6 in favor of A. In this case, therefore, job A would be the better job for the sailor in question.

To extend this logic to more than two jobs, consider the following 3-job example:

Matching Criterion	Ranked by Importance	Job A	Job B	Job C	Summed Ranks A	Summed Ranks B	Summed Ranks C
JASS	5	2	1	3	5	10	0
Moving Cost	4	1	3	2	8	0	4

NEC Reutilization	3	3	2	1	0	3	6
Fourth Criterion	2	1	3	2	4	0	2
Fifth Criterion	1	3	1	2	0	2	1

This time, instead of distinguishing the two jobs by sign, the ranks are summed for each job separately and each job is compared with every other job. Job A outranks job C (but not job B) on JASS. Hence, his total for the two together is 5. Job B outranks both A and C on JASS. Hence, summed ranks for B on JASS is (2x5=) 10. C is outranked by both of the other jobs and, therefore, scores 0 on JASS. On Moving Cost, A outranks the other two jobs and scores (2x4=) 8. B outranks neither of the other two jobs and scores 0, while C outranks B and scores 4. Overall, the Wilcoxon metric, T, is largest for A (17), second largest for B (15), and third largest for C (13).

This result is not final, of course. The Wilcoxon ranking is only a beginning. The detailer may have additional information or his own ideas about particular matches between sailor and job. Nevertheless, it is a beginning.

APPENDIX B

June 15, 2001

Mr. Tony Cunningham (N13B)
Department of the Navy
2 FB Navy Annex, Room 3602
Washington, D.C. 20370-5000

Dear Tony:

When the two of us met with you in Washington at the end of March, you indicated that you would point us a way to go after the June 4-5 workshop in Memphis. At the time of our March meeting, we had had no direct contact with any of the other players in the S/MCMS project or their ideas. As perhaps you foresaw, we came away from the Memphis meetings with many new ideas about directions we might take. This letter sketches some of those ideas.

Until June 4-5, we had focussed on developing software that would be useful to the detailer and complementary to APMS. The Memphis meetings gave us an entirely new, additional focus, namely, to model, with the detailer in the loop, ideas currently envisoned by others for the intelligent-agent approach. We were especially impressed by Bill Gates' presentation on Tuesday. Two sided auctions are something we can definitely incorporate into our software. Among other things, two-sided auctions would go a long way toward solving the horizon problem by providing a batch option to one-by-one assignment. [The detailer would decide how much of the problem to handle one-by-one and how much in batch mode.] We also have ideas about how an auction might be tweaked to allow for aggregate considerations (average moving cost, percent NECreutilization), a few extreme utilities, sailors or jobs that don't match, and the like. As we now see our effort, we would take a similar approach to other ideas ultimately intended for the Personnel Mall, for example, career paths or facilitating sailor choice or accountability.

We see two major advantages in this approach. The first is that two-sided auctions are simply a good idea. Incorporating them and other projected features of the Personnel Mall into our software will improve and strengthen it.

The second advantage is tactical. On Tuesday you underscored the obstacle we face in the "cultural barrier." Our software will hopefully include many features of the Personnel Mall and could perhaps be used successfully in a "salami" maneuver. Implementing our software would leave the detailer in the loop but also bring into play much else that was ultimately intended for

the Personnel Mall. The effect would be to get us half way. Much would be the same in our software as in the Mall except that the detailer would be standing in for the broker agent and, in some ways, for the sailor and command agents also. If our software were accepted, it might then be easier to take the next (last) step and replace the detailer with intelligent agents .

Cordially,

Marshall B. Jones

John A. Joseph. III